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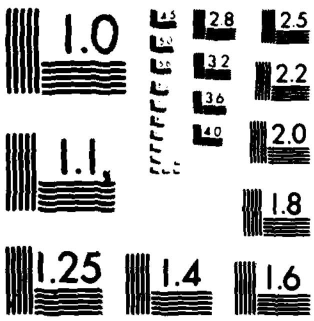

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by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

We report a versatile new technique for constructing electron tunneling junctions with mechanically-adjusted artificial barriers. I-V curves are presented for tunneling between Ag electrodes with vacuum, gas, liquid or solid in the barrier. An energy gap is apparent in the measured I-V curve when tunneling occurs between superconducting Pb electrodes.

Squeezable Electron Tunneling Junctions

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ABSTRACT

We report a versatile new technique for constructing electron tunneling junctions with mechanically-adjusted artificial barriers. I-V curves are presented for tunneling between Ag electrodes with vacuum, gas, liquid or solid in the barrier. An energy gap is apparent in the measured I-V curve when tunneling occurs between superconducting Pb electrodes.

In his Nobel Prize lecture, Ivar Giaever had this comment concerning the fabrication of tunnel junctions: "To be able to measure a tunneling current the two metals must be spaced no more than 100 Å apart, and we decided early in the game not to attempt to use air or vacuum between the two metals because of problems with vibration".[1] Though the oxide barrier junctions he subsequently made have been useful in a wide variety of scientific and practical applications, they have inherent limitations: 1) the bottom electrode can only be a metal that forms a thin, pinhole-free oxide of high dielectric strength; 2) the junction cannot, in general, be adjusted after it is made; 3) for tunneling spectroscopy, the unknown must be sandwiched between the oxide and the top electrode.

The desire to overcome these limitations has inspired numerous schemes for producing mechanically-adjusted, artificial-barrier tunnel junctions. Among them have been the landmark investigations of Young, et al.,[2-4] Teague[5,6] and Thompson and Hanrahan.[7] Most recently, beautiful surface topography has been done by Binnig, et al.[8-10]

To our knowledge, we report the first observation of a superconducting energy gap in a mechanically-adjusted, metal-insulator-metal junction. The squeezable electron tunneling junctions that we use overcome all three of the limitations mentioned above for oxide barrier junctions.

A squeezable electron tunneling (SET) junction is illustrated in Fig. 1. It consists of two crossed electrodes supported by flexible substrates separated by thin film spacers. The gap can be set by applying a force against the elastic restoring force of the flexible substrates. We found that an electromagnet works well and can be easily adapted for low temperatures. Junctions were prepared on carefully cleaned substrates in a laminar flow hood that enclosed the opening of the vacuum chamber to minimize dust.

Fig. 2. demonstrates the versatility of SET junctions by presenting I-V curves for Ag electrodes evaporated on glass microscope slides with various materials in the gap. The "vacuum" curve was obtained when a junction was adjusted in a sorption pumped vacuum chamber at a pressure of 5×10^{-3} Pa. The chamber was then vented to air to obtain the "gas" curve. The "liquid" and "solid" curves show, respectively, the results for microscope immersion oil and napthalene in the gap. These curves are reminiscent of previous results[6] in that there exist ohmic regions near zero bias with exponentially increasing currents for increasing bias.

The trend is for stability against vibration to increase with the viscosity of the material in the gap. The napthalene barrier was allowed to solidify after it was properly adjusted in the liquid state and proved to be the most stable. Its resistance could be decreased by a factor of 100 with an additional 50 N of applied force and was stable to 0.1% over time scales of minutes.

Fig. 3 shows the measured I-V characteristics of a SET junction consisting of Pb electrodes with liquid helium in the barrier. Notice the energy gap around zero bias with $2\Delta = 2.8$ meV, the appropriate value for electron tunneling between superconducting Pb electrodes.[11] The normal tunneling resistance (V > 2.8 meV) was changed from 1 MΩ to 100 KΩ by applying additional force. Assuming a barrier height of 4 eV, a junction area of 2500 μ^2 and an idealized parallel plane geometry, this resistance change corresponds to a gap change from 1.2 to 1.1 nm.[6]

One may wonder about the nature of these tunneling barriers. How much is organic contamination? How much is oxide on the electrodes? How much is liquid helium? Further investigations with tunneling spectroscopy[12] may help answer these questions.

In closing, we note that squeezable electron tunneling junctions hold promise for new avenues of research that include superconductivity, tunneling spectroscopy and the general interaction of low energy electrons with matter.

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Figure Captions

Fig. 1. A schematic illustration of a SET junction showing two electrodes supported by flexible substrates separated by thin film spacers.

Fig. 2. I-V curves obtained at room temperature for SET junctions with Ag electrode and various materials in the gap.

Fig. 3. I-V curves obtained at 1.2° K in liquid He for a SET junction consisting of superconducting Pb electrodes with different applied forces.

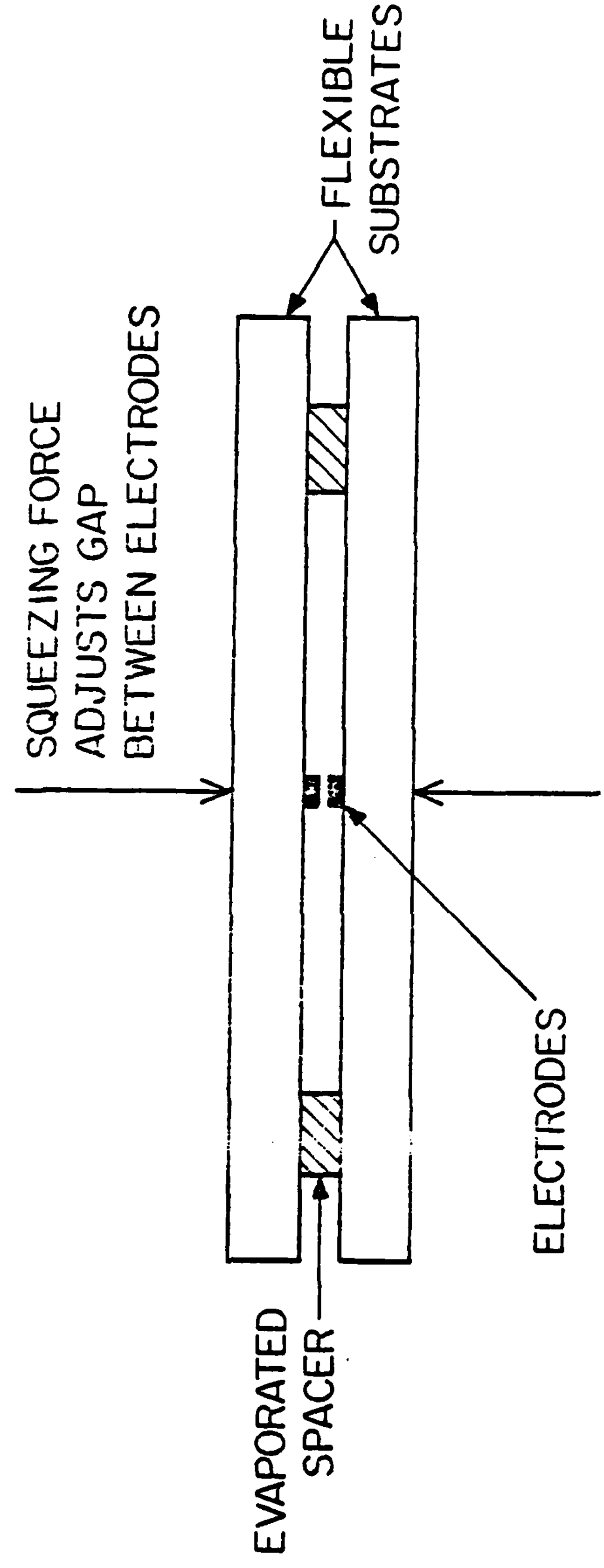

Fig. 1

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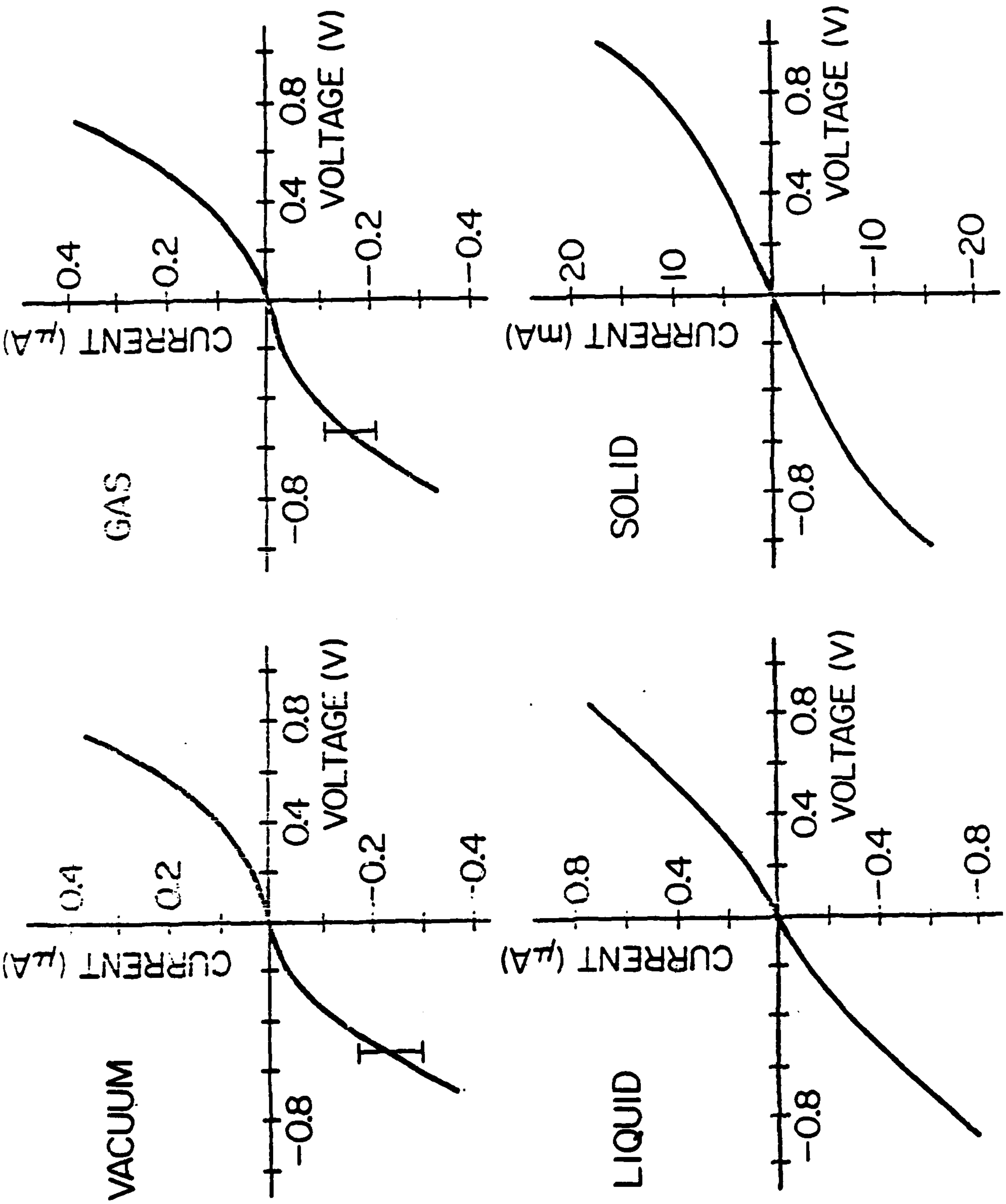

Fig. 2

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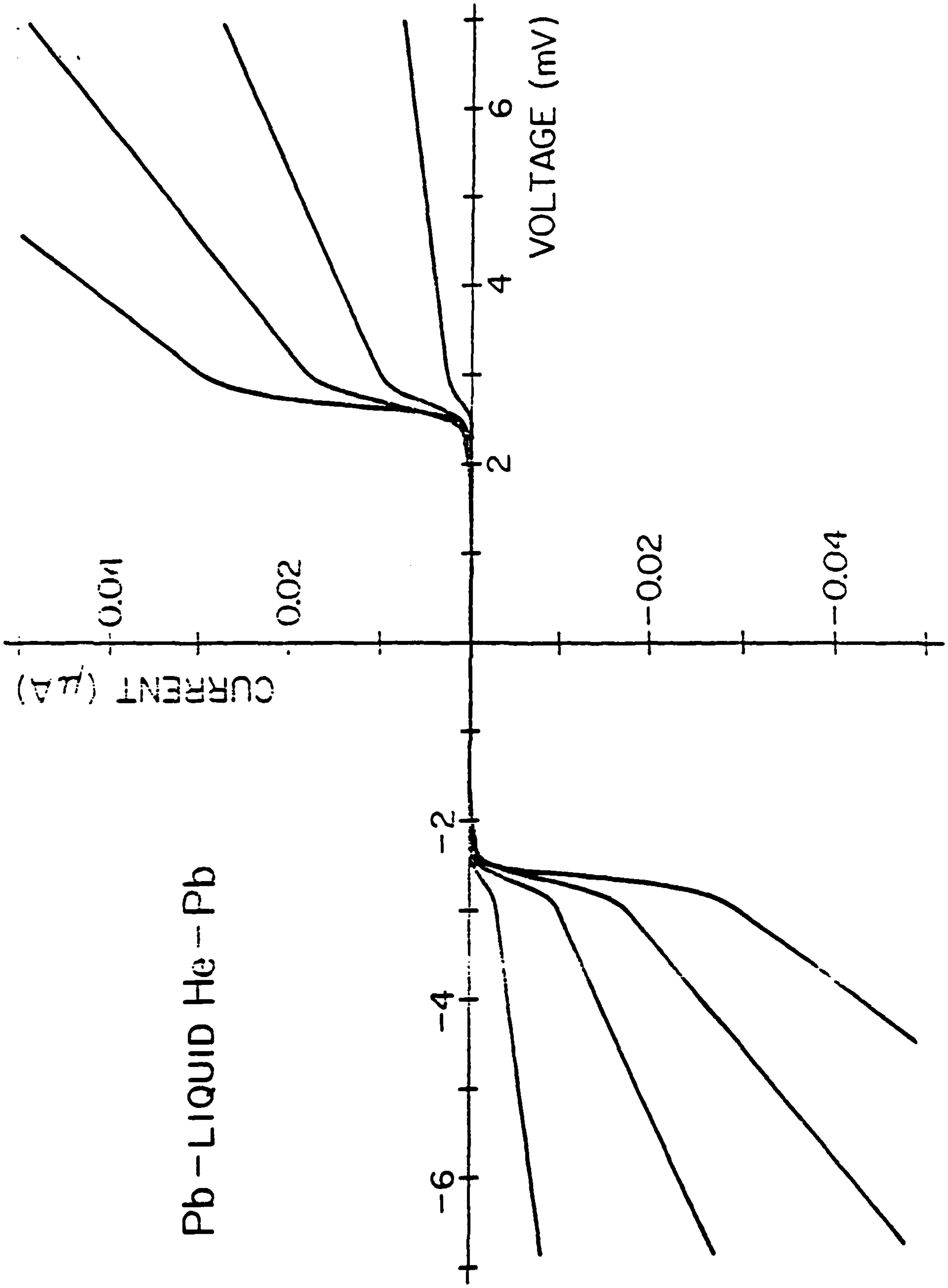

Fig. 3

Moreland, et al

10